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PATENT SPECIFICATION

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(54) WOUND DRESSING

(71) We, IMPERIAL CHEMICAL INDUSTRIES LIMITED, Imperial Chemical House, Millbank, London SW1P 3JF., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to the production of fibrillar products by the electrostatic spinning of organic materials.

The technique of electrostatic spinning of liquids, including solutions containing a fibre-forming material, is known and has been described in a number of patents as well as in the general literature.

The process of electrostatic spinning involves the introduction of a liquid into an electric field, whereby the liquid is caused to produce fibres which tend to be drawn to an electrode. While being drawn from the liquid the fibres usually harden, which may involve mere cooling (where the liquid is normally solid at room temperature, for example), chemical hardening (for example by treatment with a hardening vapour) or evaporation of solvent (for example by dehydration). The product fibres may be collected on a suitably located receiver and subsequently stripped from it.

The fibres obtained by the electrostatic spinning process are thin, of the order of 0.1 to 25 micron, preferably 0.5 to 10 micron and more preferably 1.0 to 5 micron in diameter.

We have found that the fibres, if collected to form a mat of appropriate thickness may, because of the inherent porosity of the mat so obtained, provide a non-woven wound dressing having a wide variety of applications, depending upon the composition of the fibres, their density of deposition, their diameter, and their inherent strength, and the thickness and shape of the mat. It is also possible to post-

treat such mats with other materials to modify their properties, for example to increase their strength or water resistance.

Fibres having different properties may be obtained by adjusting their composition either by spinning a liquid containing a plurality of components, each of which may contribute a desired characteristic to the finished product, or by simultaneously spinning from different liquid sources fibres of different composition which are simultaneously deposited to form a mat having an intimately intermingled mass of fibres of different material. A further alternative is to produce a mat having a plurality of layers of different fibres (or fibres of the same material but with different characteristics e.g. diameter) deposited, say, by varying with time the fibres being deposited upon the receiving surface. One way of effecting such a variation, for example, would be to have a moving receiver passing in succession sets of spinnerets from which fibres are being electrostatically spun, said fibres being deposited in succession as the receiver reaches an appropriate location relative to the spinnerets.

Thus, the present invention provides a product suitable for use as a wound dressing comprising a mat of fibres prepared by electrostatically spinning an organic polymeric material or a precursor thereof dissolved or dispersed in a liquid and collecting the spun fibres on a suitable receiver, together with a backing layer of area greater than that of the mat, the backing layer being provided with an adhesive facing, said adhesive facing being located on the same surface of the backing as the mat of electrostatically spun fibres.

Within the term mat we include deposits of electrostatically spun fibres in the form of three dimensional as well as two dimensional articles.

A particular advantage of the use of

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- materials made from the electrostatically spun fibres is that the fibres may be of very small diameter, to give a mat with small interstices and consequently a high surface area. Where the dressing is formed from a wettable polymer, blood or serum escaping from the wound tends to penetrate the dressing and the high surface area encourages clotting. Such dressings may be used as emergency dressings to halt bleeding. As examples of suitable polymers we may mention polyurethanes. Where the dressing is formed from a non-wetting polymer a particular advantage is that if the interstices between the fibres are sufficiently small, averaging, 1 to 100 μ , tissue fluids, including blood, tend not to permeate the dressing, so that the fluids are retained adjacent to the wound, where clotting will occur. Subsequent removal of such a dressing is facilitated by the absence of blood clots permeating the dressing material. Furthermore such dressings have the advantage that they are usually sufficiently porous to allow interchange of oxygen and water vapour between the atmosphere and the surface of the wound. As examples of suitable non-wetting polymers we may mention saturated polyesters e.g. polyethylene terephthalate, fluorinated compounds, particularly fluorinated hydrocarbons, e.g. PTFE, and silicones.
- Such dressings may, of course, be associated with suitable supports or reinforcement, with mats of, say, woven fibres which may have other desirable properties, or with surface or other treatment with materials having antiseptic or wound-healing properties. Blood clotting, for example, may be encouraged by incorporating clotting accelerators or inducers in or on the mat and/or on materials associated therewith in a wound dressing. Other components with which the mat may be associated include water-proof layers intended to protect the mat from undesirable effects of moisture, dirt etc.
- Preferably the wound dressing of the invention comprises a mat of flexible non-absorbent, porous, hydrophobic material, together with a non-absorbent backing layer. Such a backing layer is preferably made of hydrophobic material, but this is not essential. The dressing may also include means for applying pressure to the mat. Such means may be, for example, a stretchable elastic bandage.
- In a preferred embodiment a pad of absorbent or non-absorbent material is located between the backing layer and the mat.
- Non-adherent dressings according to the invention have been tested for efficacy by applying them to the surface of a wound on a rabbit involving loss of an area of full thickness skin, and observing the progress of healing in comparison with control wounds. A dressing made from the preferred material allowed normal healing with little or no seepage of fluid through the dressing and minimal adherence of the dressing to the scab.
- The mats are spun from a solution of or a dispersion of a polymer or its precursors. Polymers which may be conveniently spun from solution include high molecular weight fibre forming thermoplastics; in particular we would mention polyurethane, polyamides and polyacrylonitrile. Polymers which may conveniently be spun from dispersion include polytetrafluoroethylene and polyesters as well as those listed above. As an example of a polymer precursor which may be spun from solution we mention urea formaldehyde which may be cross-linked subsequent to spinning by treatment with acid vapor.
- Water soluble polymers, e.g. polyvinyl alcohol, polyvinyl pyrrolidone, and polyethylene oxide, may be spun from aqueous solution. While we do not exclude the possibility that mats prepared from such materials may be used as prepared, preferably such mats are given at least a degree of insolubility in aqueous medium e.g. by cross-linking with a suitable reagent.
- Where the mats are spun from a dispersion the spinning material comprises preferably also a solution of an additional component which acts to enhance the viscosity of the suspension and to improve its fibre forming properties. Most convenient for this purpose, we have found, is an additional organic polymeric material which subsequent to fibre formation, can, if desired, be destroyed during sintering.
- The preferred spinning material, then, is a solution or suspension which preferably comprises an organic polymer in an amount such that it is capable of forming a fibre and has cohesion properties such that the fibre form is retained during any post fibreisation hardening until the fibre has hardened sufficiently not to lose its fibrous shape on detachment from a support where this is appropriate.
- Where mats are spun from solution they comprise fibres advantageously bonded at their cross-over points and are often strong enough for use without any further treatment.
- Where mats are spun from dispersion they often have a tendency to be friable, being mere agglomerations of discrete particles held together in the form of fibres by the additional organic polymeric component present. Preferably such mats are sintered so that the particles soften and

flow into each other and the fibres may become point bonded. In the case of PTFE sintering may conveniently be carried out between 330°C and 450°C, preferably between 370°C and 390°C. Sterilisation may proceed concurrently during the sintering process. The sintering temperature in the case of PTFE is usually sufficiently high to destroy completely any undesirable organic component in the final product e.g. material added solely to enhance viscosity or emulsifying agent.

The additional organic component need, be employed only in a relatively small proportion (usually within the range 0.001 to 12% and preferably 0.01 to 3%) by weight of the suspension, although the precise concentration for any particular application can easily be determined by trial.

The degree of polymerisation of the additional organic component is preferably greater than about 2000 units linearly; a wide range of such polymers is available. An important requirement is solubility of the polymer in the selected solvent or suspending medium which is preferably water. As examples of water-soluble polymeric compounds we may mention polyethylene oxide, polyacrylamide, polyvinyl pyrrolidone and polyvinyl alcohol where an organic medium is employed to prepare the spinning material, either as the sole liquid or as a component thereof, a further wide range of organic polymeric compounds is available, for example polystyrene and polymethylmethacrylate.

We have found that generally the viscosity of the fibreizable liquid whether due solely to the presence of the fibreizable polymer or partly contributed to by the additional organic polymer should be greater than 0.1 but not greater than 150 poise. Preferably it is between 0.5 to 50 poise and more preferably between 1 and 10 poise, (viscosities being measured at low shear rates). The viscosity required using a given additional organic polymer will vary with the molecular weight of the polymer, i.e. the lower the molecular weight the higher the final viscosity needed. Again, as the molecular weight of the polymer is increased a lower concentration of it is required to give good fibreization. Thus, as examples we would mention that in the preparation of polytetrafluoroethylene mats we have found that using a polyethylene oxide of MW 100,000 as the additional organic polymer a concentration of about 12% by weight relative to the PTFE content is needed to give satisfactory fibreization, whereas with a MW of 300,000 a concentration of 1 to 6% may be adequate. Again, at a MW of 600,000 a concentration of 1 to 4% is satisfactory,

while at a MW of 4×10^6 a concentration as low as 0.2%, may give good fibreization.

The concentration of the fibreizable polymer will depend upon the amount required to provide adequate fibre properties, and will be influenced also by the need to produce a liquid of appropriate viscosity and speed of fibre hardening. Thus in the case of a dispersion we may use a concentration within the range 25% w/w to saturation, (in the case of a dispersion, "saturation" means that maximum concentration which may be included without destroying the useful spinnability of the liquid) preferably 40 to 70% and more preferably 50 to 60%, and in the case of a solution we may use a concentration within the range 10 to 60% w/w, preferably 20 to 35% w/w.

It will be appreciated that the concentration of the components must each be adjusted to take account of the presence and concentration of any other and their relative effects upon viscosity, etc.

Any convenient method may be employed to bring the spinning material into the electrostatic field, for example we have supplied the spinning liquid to an appropriate position in the electrostatic field by feeding it to a nozzle from which it is drawn by the field, whereupon fibreization occurs. Any suitable apparatus can be employed for this purpose; thus we have fed the spinning material from a syringe reservoir to the tip of an earthed syringe needle, the tip being located at an appropriate distance from an electrostatically charged surface. Upon leaving the needle the material forms fibre between the needle tip and the charged surface.

Droplets of the spinning liquid may be introduced into the field in other ways, which will be apparent to the skilled man, the only requirement being that they can be held within the field at a distance from the electrostatically charged surface such that fibreization occurs. For example they could be carried into the field on, say, a continuous carrier, e.g. a metal wire.

It will be appreciated that where the liquid is fed into the field through a nozzle, several nozzles may be used to increase the rate of fibre production. Alternative means of bringing the fibreizable liquid into the charge field may be employed, for example a perforated plate (the perforations being fed with fibreizable liquid from a manifold) may be employed.

The invention will be further described by reference to the accompanying drawings, which show, by way of Example only, further embodiments of the invention.

Figure 1 is a diagrammatic side view of apparatus for the continuous production of fibres.

Figure 2 is a perspective view of a wound dressing according to the invention.

In one embodiment the surface to which the fibres are drawn is a continuous surface, as of a drum, over which passes a belt which may be withdrawn from the region of charge, carrying with it the fibres which have been formed and which have become attached thereto. Such an arrangement is shown in the attached drawings in which Figure 1 is a diagrammatic side view of apparatus for the continuous production of fibres. In Figure 1, 1 is an earthed metal syringe needle supplied from a reservoir with spinning material at a rate related to the rate of fibres production. Belt 2 is a gauze driven by a driving roller 3 and an idler roller 4 to which is fed an electrostatic charge from a generator.

Removal of the fibre mat 6 from belt 1 is by any convenient means, for example by suction or by air jet, or it may be removed by juxtaposition of a second belt, or a second roller. Preferably it is cut and lifted off. In the Figure the mat is shown being picked up by a roller 7 rotating against the belt.

The optimum distance of the nozzle from the charged surface is determined quite simply by trial and error. We have found, for example, that using a potential of the order of 20 Kv a distance of 5—35 cm is suitable, but as the charge, nozzle dimensions, liquid flow rate, charged surface area etc. are varied so the optimum distance may vary, and it is most conveniently determined as described.

Alternative methods of fibre collection which may be employed include the use of a large rotating cylindrical collecting surface the mat being collected from another point on the surface by a non-electrically conducting pick-up means instead of being carried away on the belt.

The electrostatic potential employed will usually be within the range 5 Kv to 1000 Kv, conveniently 10—100 Kv and preferably 10—50 Kv. Any appropriate method of producing the desired potential may be employed.

It is, of course, important that the electrostatic charge is not conducted from the charged surface and where the charged surface is contacted with ancillary equipment, for example a fibre collecting belt, the belt should be made of a non-conducting material (although it must not, of course, insulate the charged plate from the fibres. We have found it convenient to use as the belt a thin Terylene (RTM) net of mesh size 3 mm wide). Obviously all supporting means, bearing etc. for the

equipment will be insulated as appropriate. Such precautions will be obvious to the skilled man.

To allow high production rates, hardening of the fibres should occur rapidly and this is facilitated by the use of concentrated fibreizing liquids (so that the minimum liquid has to be removed), easily volatile solvents for example the liquid may be wholly or partly of low boiling organic liquid) and relatively high temperatures in the vicinity of the fibre formation. The use of a gaseous, usually air, blast, particularly if the gas is warm, will often accelerate hardening of the fibre. Careful direction of the air blast may also be used to cause the fibres, after detachment, to lay in a desired position or direction. However, using conditions as described in the Examples no particular precautions were needed to ensure rapid hardening. We found that during its formation and travel from the nozzle to the belt sufficient hardening (dehydration in the case described) occurred at ambient temperature without the need for auxiliary hardening treatment.

Mats prepared according to the present invention may be between a few microns and a few centimeters thick, the choice of thickness of the mat will depend on the particular application. Suitably the thickness may be between 25μ and 1500μ preferably between 50μ and 1000μ .

The pore size will depend on the hydrophobicity of the polymer used and on the application i.e. whether adherent or non-adherent. Typical values of average pore dimension are, for an adherent polyurethane wound dressing 50 to 100μ and for a nonadherent polytetrafluoroethylene wound dressing 1 to 50μ .

The as-spun mats usually have porosities in the range 55% to 95%, which may be reduced to as low as 1% by an appropriate compressive post-treatment. The porosity will depend on the particular application, typical porosity values are, for an adherent wound dressing 80% and a non-adherent wound dressing 60%. By the term porosity we mean the percentage of the total volume of the mat which is free space.

Where dispersions are employed as the spinning material, the particle size may be between $.01\mu$ and 1μ preferably it is between $.1\mu$ and $.3\mu$.

The high surface area of the mats according to the present invention affords a method of immobilising a range of active moieties so that they are constrained to act at the site of application and do not percolate throughout the body. Moieties which may be immobilised include enzymes, drugs and active carbon. These moieties may be added to the spinning

solutions or dispersions or the mats may subsequently be treated with them.

PTFE and polyesters are the preferred polymers for non-wetting applications but we do not exclude the possibility that they be used in wettable applications after incorporation of a wettable additive. The wettable additive is preferably although not necessarily an inorganic material, conveniently a refractory material. While the wettable additive is preferably stable to body fluids and is not leached too rapidly, if at all, we do not exclude the possibility that reaction or dissolution may not in some instances be useful or desirable. The preferred additive is an inorganic oxide or hydroxide, and examples of such materials are zirconium oxide, titanium oxide, chromic oxide, and the oxides and hydroxides of magnesium and calcium, although any other suitable material or mixtures of such materials may be employed.

The following Examples illustrate the invention:—

Example 1

The apparatus was as shown in Figure 1. The belt was of "Terylene" (RTM) net 15 cm wide, the nozzle diameter was .25 mm, located 15 cm from the surface of the charged roll which had a diameter of 10 cm and width 16 cm.

To 80 gms of an aqueous dispersion of PTFE of number average median particle size 0.22 microns (Standard Specific Gravity of the polymer being 2.190) containing 3.6% weight, based on the weight of the dispersion, of surfactant "Triton X100" (Rohm and Haas) and having a PTFE solids content of 60% by weight was added 20 gms of a 10% (by weight) aqueous solution of polyethylene oxide (PEO) of average molecular weight (MW) of 2×10^5 . The final composition contained 48% by weight PTFE and about 2% by weight PEO (conductivity 1.8×10^{-4} mhos cm^{-1}).

The suspension was thoroughly mixed and fed to the nozzle by an earthed syringe injector. The electrode was charged to -20 kv and a fine jet of liquid was drawn from the nozzle and collected on the receiving surface. The fibres so collected were found to be dry and of even cross-section (1.0—2.0 μ). The fibres were very friable and the mat was removed carefully from the collector, dried at 80°C and then sintered on a bed of titanium dioxide at 380°C for 15 minutes. After this treatment the mat, 200 μ thick, was found to have retained its fibrous structure having fibres between 1 and 2 μ diameter and was quite strong.

The contact angle of the mat, measured

by a modified method of Owens and Wendt, (Journal of Applied Polymer Science 1969 13 pp 1741—1747) was 137° and in the hydrostatic head test (BS 2823) a pressure of 50 cm of water failed to penetrate the mat.

A disc of the mat 1.3 cm diameter) was applied to the surface of a wound on a rabbit involving loss of an area of full thickness skin. The rate of reepithelialisation was slightly better than that of a comparable open wound. No seepage of body fluid into the mat was observed.

The preparation was repeated to give an as-spun mat 800 μ thick, having a porosity of 83% and a pore size distribution shown in Table 1. The mat was compressed to a thickness of 300 μ for 3 min. at 100°C and 400 psi and then heated at 380°C for 15 minutes. The resulting mat was 400 μ thick and had a porosity of 59% and a pore size distribution as shown in Table 2.

Table 1
Pore Size Distribution of As-Spun Mat

| Pore Diameter (μ) | % of Pores with Smaller Diameter |
|-------------------------|----------------------------------|
| 100 | 100 |
| 60 | 80 |
| 8 | 50 |
| 2 | 30 |

Table 2
Pore Size Distribution of Treated Mat

| Pore Diameter (μ) | % of Pores with Smaller Diameter |
|-------------------------|----------------------------------|
| 100 | 100 |
| 15 | 85 |
| 2.5 | 75 |
| 2 | 67 |
| 1.2 | 50 |

Example 2

Example 1 was repeated except that 1 gm of potassium chloride was added to the spinning composition to give a conductivity of 1.2×10^{-3} mhos cm^{-1} . The resulting fibres, after sintering, had diameters of 0.5—1.4.

Example 3

Example 1 was repeated except that the polyethylene oxide had an average molecular weight of 2×10^5 . The resulting fibres, after sintering, had diameters of 0.9—1.6 μ and the mat was 50 μ thick.

The contact angle of the mat, measured as in Example 1, was 123° and the mat supported a 16.5 cm column of water.

Example 4

Example 1 was repeated except that the collecting surface was a metal gauze as

shown in Figure 2, upon which the fibre mat was supported during the subsequent sintering process.

Example 5

Example 1 was repeated except that a 10% by weight solution of a polyamide (Maranyl A100 R.T.M.) in formic acid was used as the spinning material. The fibres collected were dry and had even cross-sections (0.06—0.5 μ).

The preparation was repeated using a 16% by weight solution of Maranyl A100 in formic. The fibres collected were dry and had even cross sections (0.70—2.8 μ).

Example 6

Example 1 was repeated (without sintering) except that a 12% by weight solution of polyacrylonitrile in dimethyl formamide was used as the spinning material. The fibres collected were dry and had even cross-sections (0.8—1.4 μ).

Example 7

Example 1 was repeated (without sintering) except that a 10% by weight solution of a polyacrylonitrile/vinylidene chloride copolymer (Viclan (R.T.M.) A85/02) in tetrahydrofuran was used as the spinning material. The fibres collected were dry and of even cross-section (1.0—2.0 μ).

Example 8

A wound dressing (Figure 2) was prepared comprising a woven textile backing 12 having an adhesive surface layer 13, a pad of absorbent material 14 covered by a mat 15 of electrostatically spun material prepared as described in Example 1. The adhesive 13 of the backing is protected by cover strips 16 which are removed prior to application of the dressing.

WHAT WE CLAIM IS:—

1. A product suitable for use as a wound dressing comprising a mat of fibres

prepared by electrostatically spinning an organic polymeric material or a precursor thereof dissolved or dispersed in a liquid and collecting the spun fibres on a suitable receiver, together with a backing layer of area greater than that of the mat, the backing layer being provided with an adhesive facing, said adhesive facing being located on the same surface of the backing as the mat of electrostatically spun fibres.

2. A product according to claim 1 comprising a pad of material located between the mat and the backing.

3. A product according to claim 2 in which the pad is of absorbent material.

4. A product according to any one of claims 1 to 3 comprising electrostatically spun fibres of diameter 0.1 to 25 micron.

5. A product according to claim 4 comprising electrostatically spun fibres of diameter 0.5 to 10 micron.

6. A product according to any one of the preceding claims in which the electrostatically spun fibres are organic biologically inert polymeric substances.

7. A product according to claim 6 comprising polytetrafluorethylene fibres.

8. A product according to claim 1 comprising polyurethane fibres.

9. A product according to any one of the preceding claims in which the thickness of the mat is between 25 and 1500 microns.

10. A product according to any one of the preceding claims in which the mat has an average pore size of 1 to 100 microns.

11. A product according to any one of the preceding claims in which the mat has a porosity between 60 and 80%.

12. A product according to any one of claims 2 to 11 comprising a pad of material between the mat and the backing, in which the pad has an area smaller than that of the mat.

13. A product according to claim 1 and substantially as hereinbefore described.

B. J. BATE,

Agent for the Applicants.

Fig. 1

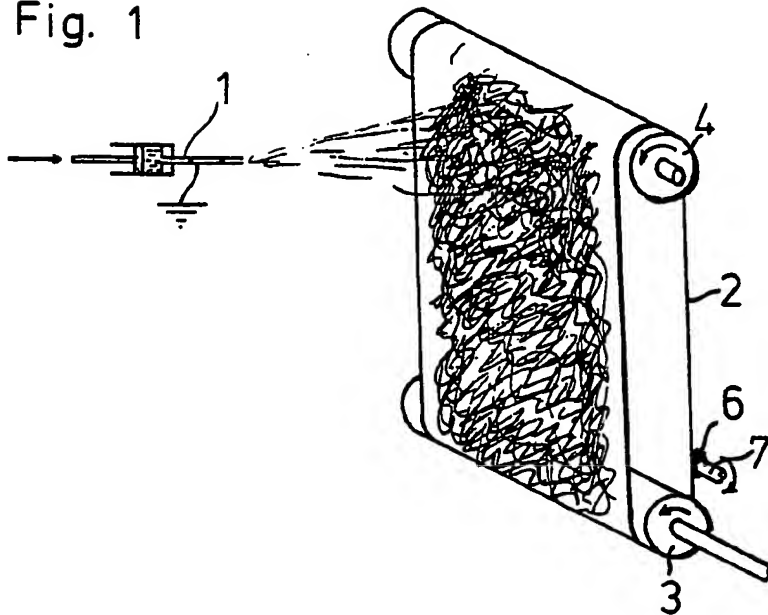


Fig. 2.

